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Toxicological Impacts of Nanoparticles on Soil and Plants

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Introduction-

Every story has two sides, and similarly, every revolution in the agricultural sector has always brought about uncertainties afterward. The anomalies that followed the green revolution included issues such as water logging, soil salinity, overexploitation of natural resources, and the use of agrochemicals, which ultimately led to a significant decrease in agricultural production (Meena *et al.*, 2020). In a similar vein, it is now time to delve into the potential of nanotechnology. Nanotechnology has the potential to impact the Agri-food sector by addressing the adverse effects of conventional practices on the climate and human health, while also improving food security and input efficiency to meet the needs of the anticipated global population increase. Moreover, it can contribute to social and economic progress (Ali *et al.*, 2014).

Nanotechnology aids in enhancing agricultural production by increasing input efficiency and minimizing losses. Nanotools, such as nanobiosensors, play a vital role in the precise management and control of inputs, thereby facilitating the advancement of innovative agriculture (Shang *et al.*, 2019). Numerous scientific studies have evaluated the effects of nanoparticles (NPs) on seed germination, growth promotion, and metabolic rate enhancement. However, it is important to note that NPs can also have negative effects, including plant growth suppression, inhibition of chlorophyll synthesis, and reduced photosynthetic efficiency. The effects of NPs can be either positive or negative, depending on the plant species, the type of nanoparticles used, and their concentration.

Nanotechnology-

- Nanotechnology is defined as the art and science of manipulating matter at the nanoscale.

- It involves the design, characterization, production, and application of structures, devices, and systems by controlling their shape and size at the nanoscale.
- Nanotechnology focuses on constructing and engineering functional systems at the atomic level, or more precisely, at a very micro-level.
- The concept of Nanotechnology was first presented by Richard Feynman in 1959. The term "Nanotechnology" was coined by Norio Taniguchi in 1974, and Heinrich Rohrer is considered the Father of Nanotechnology in India.

Advantages of nano-materials over bulk material-

- At the nanoscale, matter exhibits extraordinary properties that are not observed in bulk materials. These properties include surface area, cation exchange capacity, ion adsorption, complexation, and more.
- One of the main distinctions between nanoparticles and bulk materials is that a significant proportion of atoms in a nanoparticle are located on its surface.
- Nanoparticles have a distinct surface composition compared to larger particles, with different types and densities of sites.
- They also exhibit varying reactivity when it comes to processes such as adsorption and redox reactions.

Nano-scale-

- The term "nano" is derived from the Greek word that means "dwarf."
- Nano-scale objects are characterized by having at least one dimension (height, length, depth) measuring between 1 and 100 nanometers (1-100 nm). The nanometer scale is commonly referred to as "the Feynman scale" and is denoted by the symbol "Φ."
- One Feynman (Φ) is equivalent to 1 nanometer (nm), which is equal to 10 angstroms (Å), 10^-3 microns (µ), or 10^-9 meters (m).
- A nanometer is one billionth of a meter, roughly the width of three or four atoms.
- As an example, the average width of a human hair is approximately 25,000 nanometers.

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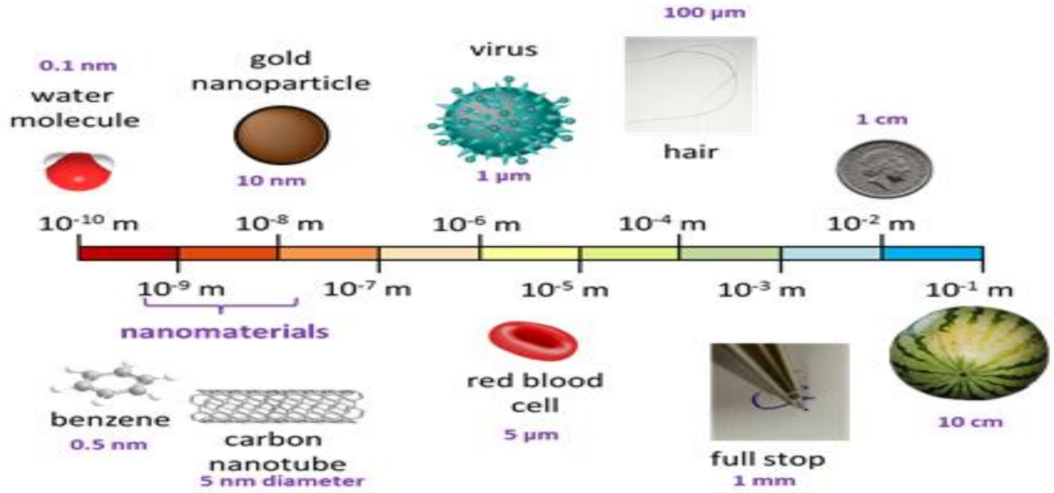
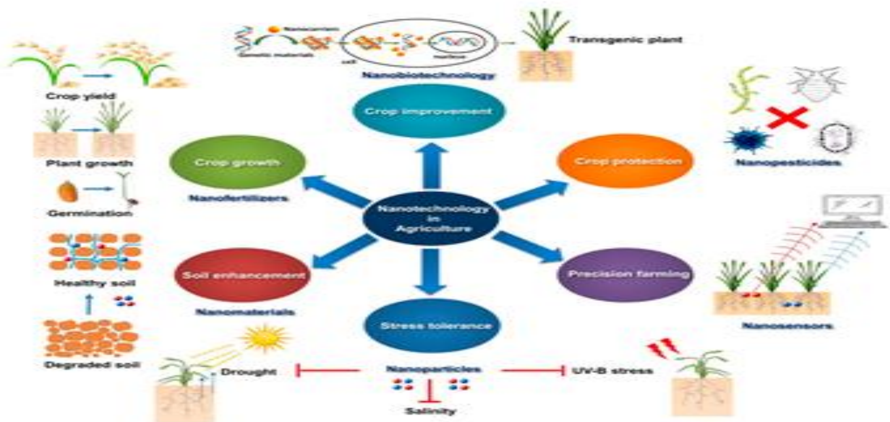


Application of nanotechnology in Agriculture-

- Nanotechnology has the potential to enhance soil quality by providing efficient nutrients, resulting in increased productivity.
- It facilitates nutrient availability to plants in a manner that meets their specific demands.
- Nanotechnology also plays a role in improving genetic traits of plants by delivering genes, DNA molecules, and drug molecules to specific sites, leading to the development of insect pest repellent properties.
- Tools such as quantum dots, based on nanotechnology, are utilized for the daily monitoring of pathogens.
- Nano encapsulation techniques help reduce the leaching and evaporation of harmful substances, thus contributing to environmental protection.

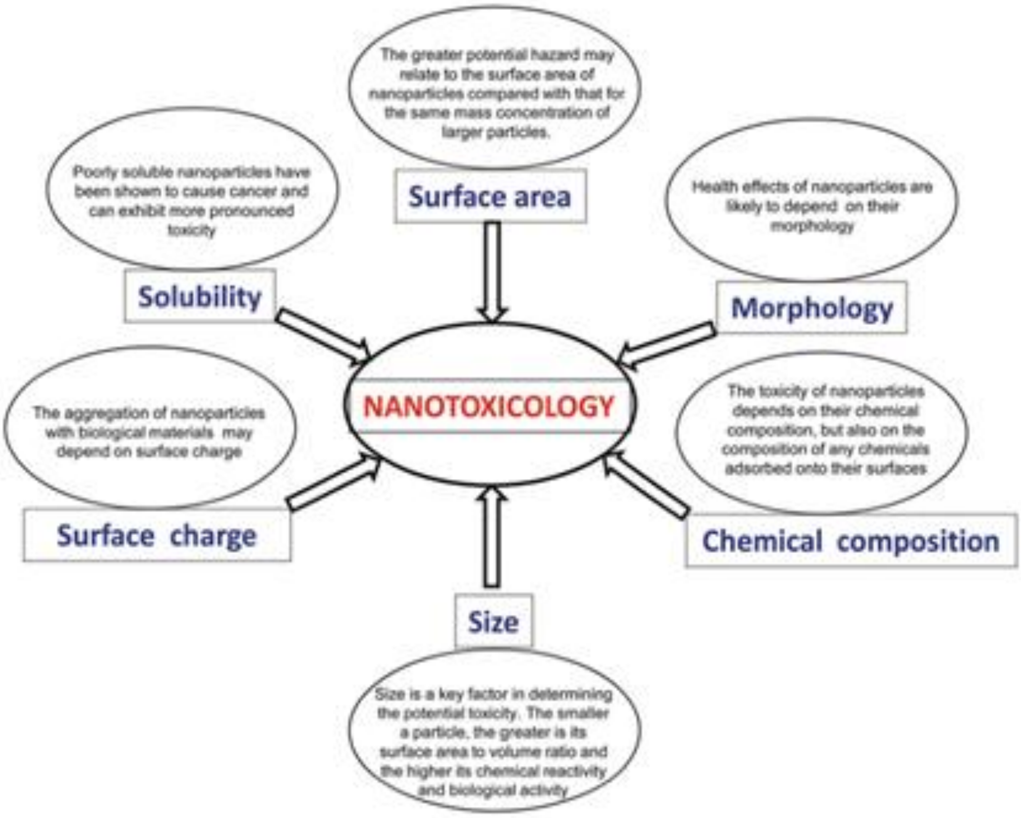


Toxicology-

- Toxicology is an interdisciplinary field encompassing biology, chemistry, and medicine that focuses on investigating the detrimental impacts of chemicals on living organisms.
- It involves the study of symptoms, mechanisms, treatments, and detection of poisoning, with a particular emphasis on human poisoning.

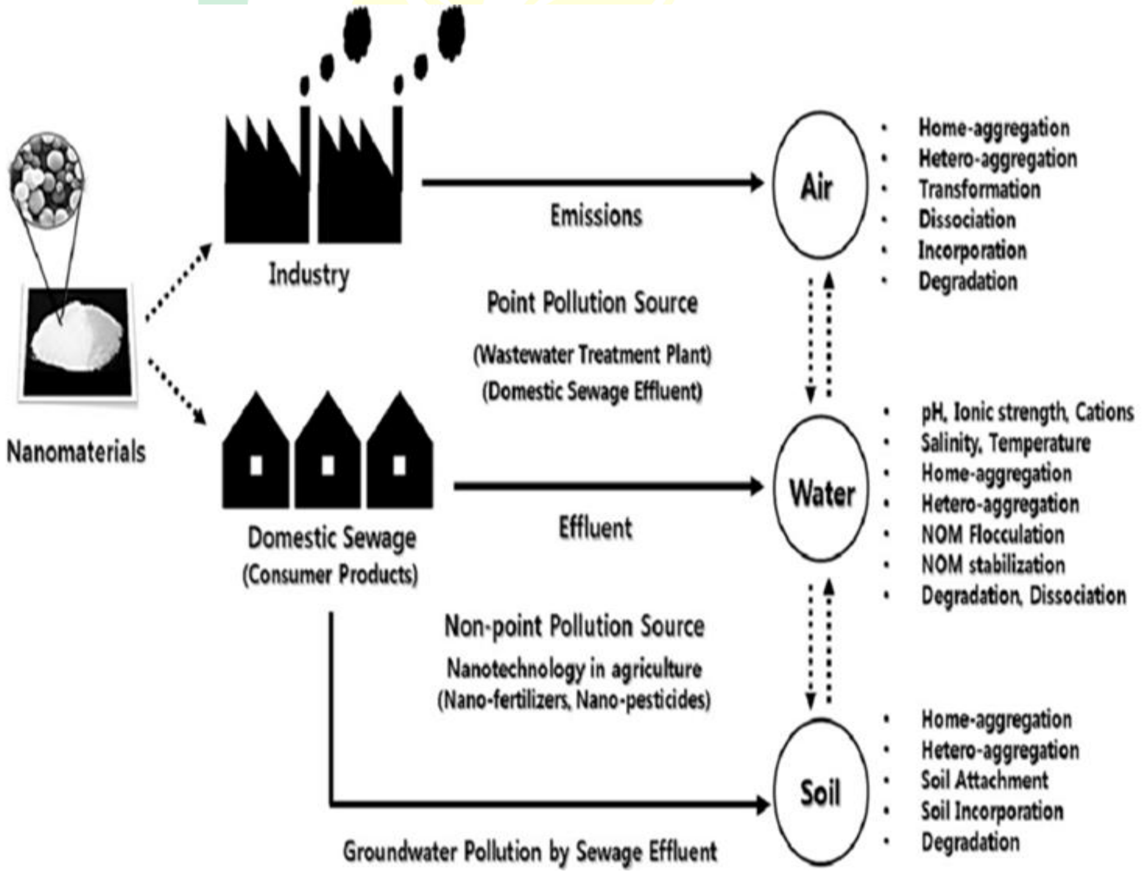
Nano Toxicology-

- Nanotoxicology is a specialized field within bionanoscience that focuses on studying and understanding the toxicity of nanomaterials. In other words, nanotoxicology examines the adverse effects of nanoparticles on the environment and its living organisms.
- The primary objective of nanotoxicological studies is to assess the potential threats posed by these unique properties of nanoparticles to the environment and human health.

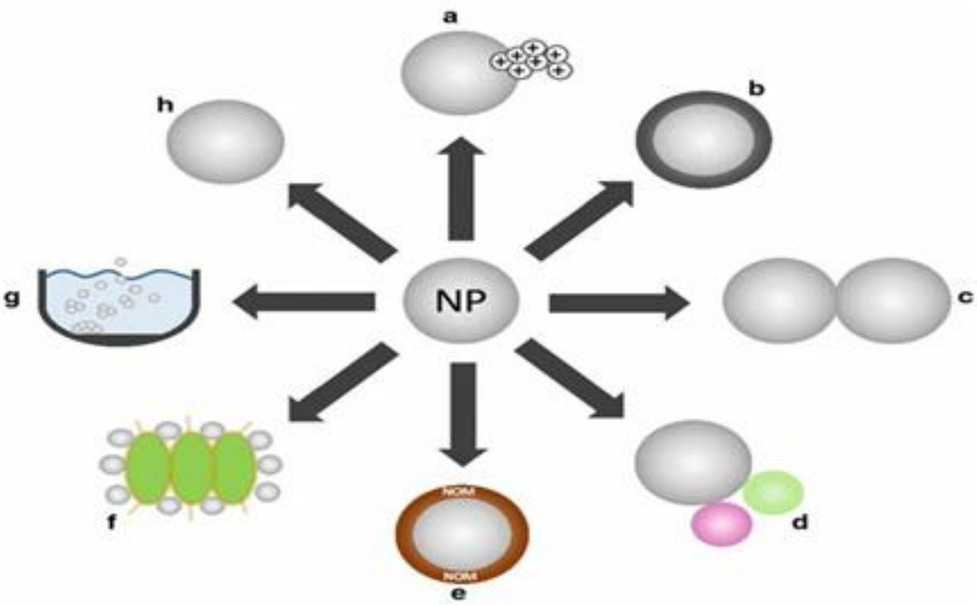


Fate of nanoparticles in environment-

- ✓ High potential threat to ecosystem and environment
- ✓ Enter the food cycle through contamination of food and water
- ✓ Deposition of nanoparticles in plant, cereals through nutrient uptake
- ✓ Foliar uptake by plants
- ✓ It may interact with other atmospheric component gases and particles like NO_2,CO_2 etc,
- ✓ It may undergo agglomeration or aggregation in the atmosphere
- ✓ There are various physical and chemical characteristics or factors which influence the fate of airborne particle in atmosphere.
- ✓ The processes which control the potential atmospheric transport of particles are agglomeration, diffusion, wet and dry deposition and gravitational setting.
- ✓ Airborne particles can be classified by size and behavior into three general groups small particles = <80 nm, intermediate sized particles = 80-2000nm and large sized particles = >2000 nm



Interactions and fate of NP in the environment-



Interactions and fate of NP in the environment considering (a) dissolution (b) sulfidation (c) homo-aggregation (d) hetero-aggregation (e) coating with NOM (f) NP adsorption on biological surfaces (g) sedimentation/deposition (h) persistence

Dissolution-

- The dissolution of nanoparticles (NP) is primarily influenced by the particle's chemistry.
- For instance, the dissolution of silver nanoparticles (Ag NP) occurs under aerobic conditions.
- In such environments, an oxide layer (Ag2O) can form around the particle, leading to the release of silver (Ag).
- Various studies have revealed that the dissolution rates of Ag NP are influenced by intrinsic factors such as surface coating, size, shape, and aggregation state of the particles, as well as environmental parameters including pH, dissolved organic carbon, and temperature.

Sulfidation-

- Sulfidation of nanoparticles (NP) results in surfaces that are nearly inert, impacting their reactivity and potential toxicity. However, it is important to note that even sulfidized NP can still exhibit toxicity towards microorganisms.

Homo-aggregation-

- The homo-aggregation of nanoparticles (NP) is directly influenced by their concentration in the surrounding media.
- In the case of surface waters, the predicted environmental concentrations are generally low, ranging from pg/L to low µg/L, which reduces the likelihood of homo-aggregation due to the low probability of collisions.
- The dynamics of aggregation are commonly characterized by the classical Derjaguin-Landau-Verwey-Overbeek (DLVO) theory.
- Apart from ionic strength, homo-aggregation is also influenced by various environmental variables.

Hetero-aggregation –

- The higher concentration of natural colloids compared to nanoparticles (NP) makes natural colloids more environmentally significant.
- Hetero-aggregation, which involves the interaction between different types of particles, is the primary mechanism responsible for removing CeO2 NP from the water phase through sedimentation.
- The aggregation kinetics between NP and natural colloids or other NP are particularly rapid when they have different charges. However, the presence of natural organic matter (NOM) reduces hetero-aggregation due to electrostatic and steric stabilization.
- Apart from electrostatic forces, mechanisms such as polymer bridging, hydrogen bonding, and chemical bonding have been reported to induce hetero-aggregation.
- Hetero-aggregation is a highly complex process influenced by various factors including the surface properties of the NP, their aging status, the particulate phases they interact with, the chemical composition of the surrounding environment, as well as the properties of natural inorganic, organic, and biological colloids.

Coating with NOM-

- The significance of natural organic molecules attaching to nanoparticles (NP) has been recently reviewed elsewhere, and here we provide only a few examples.
- Dissolved organic matter (DOM) coats NP, leading to the stabilization of particle size through steric or electrostatic repulsion. These processes are more effective when the

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DOM exhibits increased hydrophobicity or aromaticity, ultimately reducing the ecotoxicological potential of the NP by limiting the availability of reactive surfaces.

- When artificial (e.g., polyvinylpyrrolidone, gum arabic, or citrate) or natural organic matter (OM) coats silver nanoparticles (Ag NP), the release of potentially toxic ions into the surrounding environment is reduced, as is the NP bioavailability.
- Conversely, humic acid has been found to increase the release of ions from lead nanoparticles (Pb NP). Soil and soil-water extracts can enhance the effects of NP compared to their absence.

NP adsorption on biological surfaces-

- The feeding of algal cells to invertebrates has the potential to increase the uptake and toxicity of nanoparticles (NP).
- NP can absorb onto the surfaces of algal cells, leading to accelerated sedimentation. This, in turn, requires pelagic consumers to expend more energy in obtaining their food near the sediment.

Sedimentation-

- The adsorption of nanoparticles (NP) onto algal cell surfaces can result in the accelerated sedimentation of algal cells. This, in turn, places additional pressure on pelagic consumers as they are forced to invest more energy in obtaining NP-contaminated food near the sediment.
- The ingestion of NP along with food can have adverse effects on digestion for pelagic consumers, as the NP may clog the gut. This can have negative consequences on the life history strategies of primary consumers in autotrophic food webs.

Fate of nanoparticles in plant and soil-

- The fate of nanoparticles (NP) in the soil is determined by their chemical and physical properties.
- Due to their high surface area, NP are strongly absorbed by the soil.
- Once in the soil, NP can either become immobile or potentially move faster than larger particles before getting trapped in the soil matrix. This is because NP are small enough to fit into the small spaces between soil particles.

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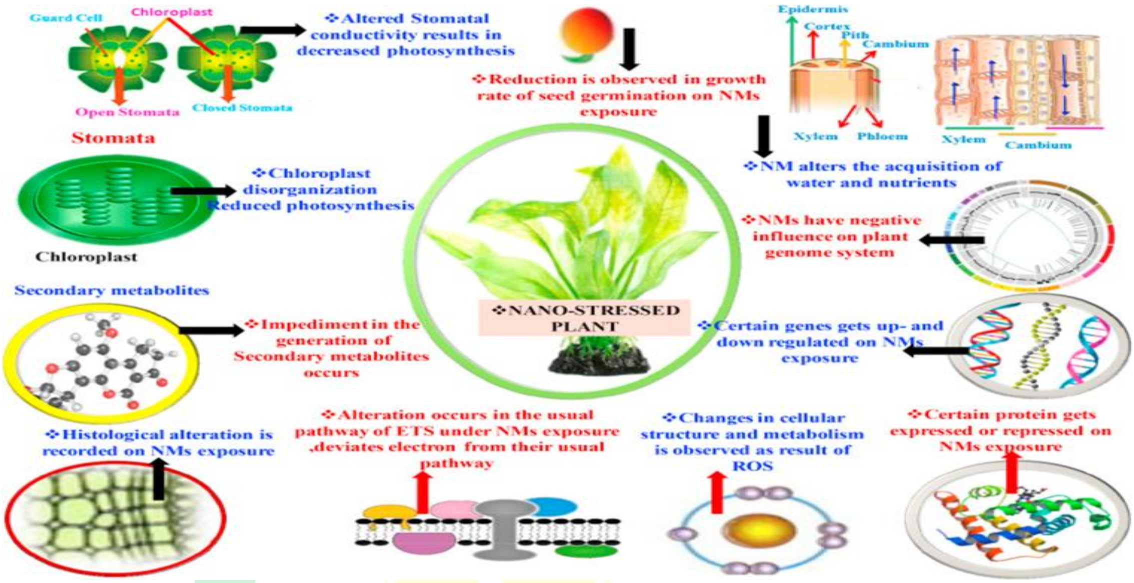
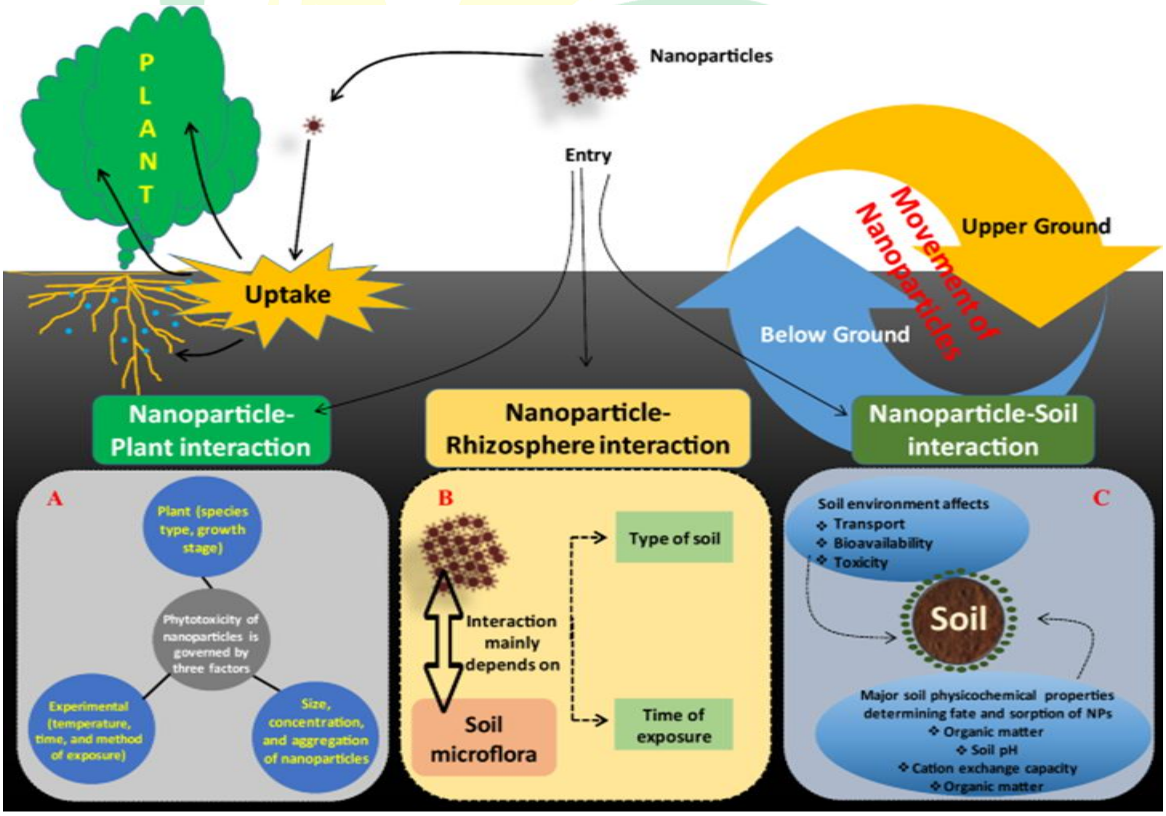
- The rate of NP absorption within the soil depends on factors such as their size, chemistry, surface treatment, and the specific conditions under which they are applied.





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Conclusions-

- Nanoparticles pose potential threats to agriculture, particularly in relation to soil and plants.
- Many nanoparticles exhibit phytotoxicity and can pose hazards to soil microbial biodiversity when exposed to higher levels.
- Improper handling of this technology can result in serious negative effects on the agricultural ecosystem.
- The disruption of the agricultural ecosystem could indirectly impact human health in the future.

Future Perspectives –

- **Research:** The integrated study of nanoparticles and their toxicological impacts on the environment is essential.
- **Policy:** There is a need for the development of a national policy that promotes the safe handling and judicious use of nanoparticles in agriculture.

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